

A SYSTEM FOR MANAGING NETWORKED INFORMATION CONTENTS

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to a computer-implemented system that supports effective coordination of geographically, and/or functionally distributed human tasks (i.e., operations, processes, and decision making etc) as well as computer-programmed tasks, by developing and managing, over the Web, networked information contents that support those tasks.

2. PRIOR ART

Information contents constructed and viewed on the Web are represented in Web-standard languages such as HTML and XML. Units of information written in such languages are called "Web documents". The most important characteristics of Web documents are their ability that information contents in these documents can be decomposed in a tree-like hierarchical structure, and that each component in such a decomposition can have semantic description and attributes through syntactic construct called "tag". While tags in HTML are for layout interpretation only and not extensible, tags in XML are extensible and can accept any interpretations the user defines. In HTML and XML, information contents that can

be identified as decomposed components via tags are called "elements".

Through Fig. 1 below, we will illustrate elements and their hierarchical structure in XML. In the figure, the part `<CompanyName> ABC Paper Mill </CompanyName>`, for instance, is an example of element. `<CompanyName>` is an open tag, and `</CompanyName>` is a closed tag. An element can have its own internal tree structure, and it can contain another element in it. In this case, the latter element is called a "sub-element" of the former. For instance, in Fig. 1, the part beginning with the open tag `<Work>` and ending with the closed tag `</Work>` is an example of an element having its own internal structure. Elements such as `<CompanyName> ABC Paper Mill </CompanyName>` and the part beginning with `<FatherContactAtWork Cname="C1" >` and ending with `</FatherContactAtWork>` are examples of sub-elements of the `<Work>` element. Furthermore, the latter sub-element has its own sub-elements such as `<DirectPhone> 025 432 3229</DirectPhone>`. A sub-element of a sub-element of an element is also a sub-element of this element. For instance, `<DirectPhone> 025 432 3229</DirectPhone>` is also a sub-element of the `<Work>` element. In XML, various attributes can be defined for elements. More specifically, an attribute can be defined for an element in its open tag

in the form Attribute Name = "Attribute Value". In Fig. 1, through the open tag <FatherInfo DateUpdated= "February 1, 2000">, the "FatherInfo" element is given an attribute, "DateUpdated", and its value, "February 1, 2000".

Web-standard languages such as HTML support "links" that relate elements of Web documents, and a network of information contents can be developed via such links. Moreover, XML and its related standards such as XLinks support linking capabilities far superior to those offered in HTML.

However, links are a mechanism for moving from one piece of information content to another, and not intended to capture "dependency relationships" that might exist between such pieces of information contents. A critical difference between links and dependency relationships is that in dependency relationships, there is the notion of "interpretation" between related pieces of information contents. For instance, an engineer responsible for development of a product is likely to have a certain specific use of sales data about the product. Thus, it is desirable to analyze and customize the sales data for his intended use. If this analysis and customization can be captured computationally, we say that the customized data functionally depends on the original sales data. It is not possible to directly represent such dependency relationships

using linking mechanisms of Web-standard languages such as XML or XLinks.

Currently, such dependency relationships are represented using programming languages such as Java or scripting languages such as Java Script (from here on, we use the term "programming languages" to refer to scripting languages as well).

However, there are several problems and difficulties associated with representation of dependency relationships using programming languages:

- Representational Independence: When precise representations of dependency relationships depend on particular programming languages, their representational independence from specific implementations is difficult to maintain. If the deployed programming language changes, the existing representations of dependency relationships may possibly become invalid.
- Sharing: One must know a specific programming language sufficiently well in order to understand the precise definitions of dependency relationships given in the programming language. It is difficult to share dependency relationships and organizational knowledge captured in such dependency relationships.
- Flexibility in maintaining and managing existing

dependency relationships: Once dependency relationships get coded in a programming language, it will be more difficult to adjust and modify them, and consequently the resulting information system tends to be rigid.

- Uniformity: Since there is no established, uniform representation format for dependency relationships, it is difficult to maintain uniformity in representation of dependency relationships, and hence also difficult to evaluate a chain of multiple dependency relationships. For instance, suppose we have information contents A, B and C. If we have different representation formats for a dependency relationship from A to B and another dependency relationship from B to C, we would have to have multiple evaluation environments, and it would be more difficult to evaluate the chain of relationships from A to C (via B) without interruptions.
- Consistency: When no uniform representation format is established for dependency relationships, it will be difficult to maintain the consistency of entire information contents networked through such relationships. More precisely, the difficulty is with consistent propagation of updates throughout the dependency chain of information contents whenever a change occurs in some part of the networked information contents.

Now, we shift to the issue of interface for editing and viewing information contents over the Web. The notion of "port" as a relay point or interface for information interchange has been around for a long time. For instance, telephone is an example of a port, as well as email over the Internet. These are a kind of 'general-purpose" ports in the sense that they receive unspecified information from unspecified sources. In contrast, with the advent of the Web, it is becoming increasingly feasible to construct ports specialized for particular needs. For instance, a company may have Web pages customized for individual clients, through which each client can obtain customized information or send his own order inquiries. These are beginning examples of "special-purpose" ports.

However, as the intended use of a port gets more specialized, so does the role of the port within the entire context of a task the user of the port is expected to accomplish. In such cases, the user would have to have a collection of special-purpose ports to complete his task. However, a framework for organizing a collection of related ports intended to support a complete task has not been developed yet. For instance, a product development engineer as in the example above might need a port for receiving sales information from the sales department, a port for receiving

information on production process from production lines, and also a port for sending information to production lines. We would need a framework for managing such a collection of ports as a coherently organized "port complex", with its coherence stemming from the fact that all of these ports are intended to support a common task collectively.

At this point, the idea of building a port complex over the Web has not been systematically developed. The present practice of information interchange over the Web for the purpose of coordinating organizational tasks has the following technical difficulties and problems:

- Layout discontinuity of related ports: For instance, in the case of placing orders over the Web, the port for sending orders and the port for receiving order confirmation should reside in the same port complex as they serve the same task of order-placing. However, in most cases, the two ports are represented as separate Web documents, and hence the user needs to go back and forth between multiple documents in order to complete his task. In other words, the layout continuity of use-wise related ports has not been well established. The layout and operational "distance" between related ports should solely depend on the amount of information being presented in those ports.

- Ineffective, mixed representation of related ports: A port complex has several aspects or features. They are, for instance, information contents in the complex, types of ports in the complex, input and control functions of ports, and layout of the complex. If HTML is used to build a port complex, all of these aspects or features will be mixed in one file, and people with HTML knowledge would have to deal with all of those aspects or features. Obviously, this is not a very effective way of building a port complex. XML, on the other hand, separates information contents from layout presentation, and hence port layout can be specified in a separate file using a layout specification language such as XSL. Even in XML representation of a port complex, however, unless those aspects or features are well distinguished at least conceptually, disadvantages of HTML-based development would still persist.

SUMMARY OF THE INVENTION

An overall objective addressed by the invention is to construct a network of information contents including their dependency relationships over the Web and realize a mechanism of update propagation throughout the network so that a collection of human or computer-based tasks distributed geographically and/or organizationally can be coordinated

effectively through dissemination of right information at right time over the Web. A more specific objective of the invention is to improve the way in which dependency relationships of information contents are represented by establishing representational uniformity, representational independence from specific programming languages, ease of sharing dependency relationships as organizational resource, and increased flexibility in modifying dependency relationships. Another more specific objective of the invention is to maintain the consistency of information contents of the entire network through uninterrupted execution of update propagation and management. Another more specific objective of the invention is to improve the efficiency of update propagation by analyzing the dependency structure of information contents prior to the propagation. Another overall objective of the invention is to construct, over the Web, a port complex, i.e., a collection of related ports for receiving and sending information. A more specific objective of the invention is to remove unnecessary inter-port "distances" that result from the current practice of implementing ports in which contents of separate ports, even when they are use-wise related, are represented in different Web documents. Another more specific objective of the invention is to improve the efficiency of port complex

construction by distinguishing and separately defining different aspects or features of a port complex. Another more specific objective of the invention is to develop, over the Web, a networked collection of port complexes on top of a collection of information contents networked through their dependency relationships.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an example of a content file in which some content variables are declared;

Fig. 2 is another example of a content file in which some content variables are declared;

Fig. 3 is an example of a content file in which functional dependent variables are declared;

Fig. 4 is another example of a content file in which functional dependent variables are declared;

Fig. 5 is an example of a content file after execution of the definition of a functional dependent variable;

Fig. 6 is an example of a constraint file;

Fig. 7 is another example of a content file after execution of the definition of a functional dependent variable;

Fig. 8 is another example of a constraint file;

Fig. 9 is an example of a content net in which dependency

relationships among elements are specified in a single file separate from Web documents representing information contents;

Fig. 10 is an example of a content net that is given as a collection of pairs of a content file and its constraint file;

Fig. 11 is an example of a station;

Fig. 12 is an example of a station net; and

Fig. 13 shows a form of the content net update propagation system.

Detailed Description of the Preferred Embodiments

A "content net" is a collection of Web documents having dependency relationships among their elements. It is assumed that dependency relationships among document elements in a content net are given representations that permit computer-based interpretation and evaluation.

Elements involved in one or more dependency relationships in a content net are called "active elements". Active elements that do not depend on other elements are called "initial elements". Contents of an initial element are entered or updated by human users of the content net, or by application programs external to the content net such as database applications. Given a content net, a

computer-implemented system that updates all elements that directly or indirectly depend on one or more updated initial elements is called a "content net update propagation system".

Given a content net, it is assumed that all of its active elements are given some form of unique identifiers. One possible form of such identifiers is, for instance, a path in the tree structure of a Web document from its root node to the active element to be identified. Such paths can be represented in languages under Web standardization effort such as XPath or XPointers. Another form of identifiers for active elements can be realized via values of a designated attribute given to active elements. For the sake of a concrete description of the invention, we use the latter, attribute-based identification using the "Cname" attribute, but actual implementations of such identifiers are not limited to this form. Values of the Cname attribute are called "content variables". In the example of Fig. 1, the element "FatherContactAtWork" is given the content variable "C1" via its open tag <FatherContactAtWork Cname="C1" >. Dependency relationships in a content net can then be represented as relationships among such content variables (or other forms of identifiers for active elements).

Fig. 9 shows an example of a content net with dependency relationships defined via element identifiers (not

necessarily implemented as content variables). In the example, identifiers for active elements are shown as "a.x", "a.y", etc, and dependency relationships among active elements are defined functionally via functions F_1 through F_8 and element identifiers. In Fig. 9, there is only one constraint file containing all dependency relationships. But, this is only one specific form of representing dependency relationships, and it is also possible to allocate dependency relationships to multiple constraint files. For instance, each content file can be paired with a constraint file, which defines dependency relationships for active elements in the paired content file. Fig. 10 illustrates content nets of this type. Yet another form of representation for dependency relationships may not have separate constraint files at all, and may capture dependency relationships directly in content files themselves. Especially, when Web documents representing information contents are written in XML, or when those Web documents permit XML-based tagging at least partially, mixing dependency relationships with contents in content files can be done rather easily.

For the purpose of propagating updates through dependency chains of active elements, the constraint file in Fig. 9 can be actually a computer program written in a programming language such as Java, or it is also possible

to develop a system that can interpret and execute dependency specifications in the constraint file. Then, functions such as F_1 can be processed by a programming language or by such a system. In the latter case, it is also possible to process such functions via external application software as long as the following holds:

- A read-write interface can be developed between the application software and Web documents.
- The read-write interface including initiation of the application software can be controlled via a program external to the application software.

When functions such as F_1 are implemented via external application software, the content net update propagation system can serve as a system for coordinating various applications through exchange of messages represented as elements of Web documents.

Next, the content net update propagation system will be described in further details. In what follows, content variables will be used as preferred identifiers for active elements, and the implementation of a content net as a collection of pairs of a content file and its associated constraint file (as in Fig. 10) will be deployed, but this choice is only one form of implementation.

Suppose that a content variable C is assigned to an

active element in a content file X. In this case, we say "C is declared in X", and call that active element a "C element". An active element can have another active element as its sub-element. Suppose an active element B is a sub-element of an active element A. If there are no other active elements between A and B (i.e., in the path from A down to B), we say that B is a direct, active sub-element of A.

Each dependency relationship among content variables in a content net is defined in a "dependency clause". A dependency clause is represented in the following form, or a form equivalent to this form:

$[C_0, \{C_1, C_2, \dots, C_n\}, d],$

where $C_0, C_1, C_2, \dots, C_n$ are all content variables. The intended meaning of such a dependency clause is that the content variable C_0 is defined in terms of content variables C_1, C_2, \dots, C_n via the third term d of the clause. A dependency clause in which a content variable C is defined is called a "C-clause". A content net assumes that for each content variable, if there is a dependency clause defining that content variable, that dependency clause is the only clause defining the variable. A content variable having no dependency clause defining it is called a "free variable". Thus, a free variable corresponds to an initial element, which does not depend on other active elements, and it serves as an interface to

receive information from human users or applications external to the content net.

There are two types of dependency clauses: "functional dependency clauses" and "hierarchical dependency clauses". Functional dependency clauses must satisfy the following:

- The third term d of the clause is a functional expression consisting of content variables C_1, C_2, \dots, C_n , MathML operators, and external operators that can be referenced in MathML.
- Different content variables in the first and second terms of a dependency clause can be declared in different content files. However, for any content variable C_i in the second term of the clause, there is no sub-element relationship between C_0 and C_i .

Hierarchical dependency clauses, on the other hand, must satisfy the following:

- The third term, " d ", of the dependency clause represents the null operation, which may be denoted by a designated symbol such as "null".
- C_0 is declared in some content file, in which C_1 -element, C_2 -element, ..., and C_n -element are direct active sub-elements of C_0 -element and they are the only direct active sub-elements of C_0 -element.

The content variable in the first term of a functional

dependency clause is called a "functional dependent variable" or simply "dependent variable". The content variable in the first term of a hierarchical dependency clause is called an "aggregate variable". Suppose that a content variable C is defined in some dependency clause. By the assumption above, we have only one C- clause. Thus, C may be either a dependent variable or an aggregate variable, but not both at the same time. Also, if the C-element has active sub-elements, C must be an aggregate variable defined in a hierarchical dependency clause. Thus, a dependent variable has no active sub-elements.

Hierarchical dependency clauses are determined by hierarchical relationships among active elements in a content file. In contrast, functional dependency clauses are defined directly in constraint files. In order to illustrate functional dependency, we will introduce 3 content files in Fig. 2, 3 and 4 (in addition to the content file in Fig. 1). Consider the following functional dependency clauses in the context of 4 content files in Fig. 1, 2, 3, and 4:

[Z, {C2, H2}, C2+H2]

[W, {C1, H1}, buildTree(C1, H1)]

The first dependency clause [Z, {C2, H2}, C2+H2] is given in a constraint file (Fig. 6) that pairs with the

"SatoBookkeeping" content file. The second dependency clause $[W, \{C1, H1\}, \text{buildTree}(C1, H1)]$ is specified in the constraint file (Fig. 8) that corresponds to the "SatoTelephoneDirectory" content file.

The meaning of the dependency clause $[Z, \{C2, H2\}, C2+H2]$ is that the content "10,000,000" denoted by C2 (Fig. 1) and the content "8,000,000" denoted by H2 (Fig. 2) are added together and that the resulting sum is the content of Z. Thus, once this dependency clause gets interpreted and executed according to its meaning described above, the "SatoBookkeeping" content file will be updated as in Fig. 5. The actual mechanism of interpreting and executing dependency clauses will be described in later sections.

The operator "buildTree" in the second dependency clause $[W, \{C1, H1\}, \text{buildTree}(C1, H1)]$ is an example of an external operator that can be accessed in MathML. Its meaning in this example is to build a new tree by concatenating, under a new root node, existing trees denoted by C1 and H1 in that order. So, once this dependency clause gets interpreted and executed, the "SatoTelephoneDirectory" content file will be updated as in Fig. 7.

Given a content net, its "dependency graph" is a collection of all functional dependency clauses defined in the constraint files of the content net and hierarchical

dependency clauses given by hierarchical relationships of active elements in the content files of the net. The "dependency graph construction module" is a system module that, given a content net, computes its dependency graph by extracting all functional dependency clauses from the constraint files and all hierarchical dependency clauses from the content files (see Fig. 13). When a content variable A depends on a content variable B, which in turn depends on a content variable C in a dependency graph, we say A indirectly depends on C, or simply A depends on C. Given a dependency graph, its "dependency matrix" identifies for each content variable in the underlying content net, all content variables that directly or indirectly depend on that content variable. More specifically, if the number of content variables in a given content net is n in total, its dependency matrix can be represented as an $n \times n$ matrix indexed by the set of all content variables in the content net. In this case, given content variables C_1 and C_2 , the matrix entry (C_1, C_2) indicates presence or absence of the dependency relationship between the two content variables. Such a dependency matrix can be computed from a dependency graph through a known algorithm. The "dependency matrix construction module" is a system module that computes a dependency matrix, given a dependency graph (see Fig. 13). A dependency matrix can detect a cyclic

dependency chain in which a content variable indirectly depends on itself. When a cyclic dependency chain exists, a system that propagates updates along dependency chains will be trapped in an infinite loop. The "cyclic dependency detection module" is a system module that detects and reports cyclic dependencies given a dependency matrix (see Fig. 13). Given a set of free variables, its "update candidate set" is a set of content variables that directly or indirectly depend on some variables in the set. The "candidate set generation module" is a system module that, given a set of free variables, computes its update candidate set. Free variables are clustered together whenever they are intended to be updated together and belong to the same update scope. For instance, in an order-placing task, if different content variables are assigned to elements representing order items, order quantities and order dates, these content variables collectively represent a single unit of updates. Whenever such update scopes naturally exist, corresponding update candidate sets can be pre-determined prior to the actual propagation of updates. We will put together four system modules discussed above, namely, the dependency graph construction module, the dependency matrix construction module, the cyclic dependency detection module, and the candidate set generation module, and call it the "dependency

structure analysis module".

An update request by the user of a content net consists of a set of free variables and an update content for each of these free variables. Given an update request, the dependency structure analysis module determines the update candidate set that corresponds to the set of free variables in the request. The "update module" is a system module that, given an update candidate set, updates active elements associated with content variables in the update candidate set, following the dependency structure of the candidate set. The update module can be implemented in a variety of ways, but two main types of methods are top-down methods and bottom-up methods. A top-down method can be realized via a known recursive algorithm. Given an update candidate set, a top-down method recursively searches for "update-ready" content variables, and whenever it finds such content variables, it updates corresponding active elements. Here, a content variable C is said to be "update-ready" with respect to a set, say S , of content variables which have been already updated if it satisfies the following:

- C directly depends on at least one variable in S ;
- Whenever C directly depends on a content variable D not in S , D does not depend on any variable in S (i.e., D is not affected by S).

Such top-down modules are relatively easy to implement, and they are probably reasonably efficient when dependency chains are shorter. When dependency chains are longer, pre-computing update-ready variables will be effective. Namely, first we identify the set of all update-ready content variables with respect to the set of free variables in the update request. We assign an "update rank", or simply "rank" 0 to the set of free variables in the request, and a rank 1 to the set of update-ready variables with respect to the set of free variables. Next, we identify the set of all update-ready variables, this time with respect to the set of all content variables with rank 1, and assign rank 2 to all update-ready variables newly identified. The update-ranking module is a system module that, given an update candidate set, computes ranks for all content variables in the set by repeatedly applying the procedure described above. The update-ranking module can efficiently compute update ranks by using a dependency matrix. In the example of Fig. 9, the update-ranking module will determine the following ranking of content variables:

Rank 0: a.x, c.y, d.z

Rank 1: d.x, d.y

Rank 2: b.y, c.x

Rank 3: b.z

Rank 4: a.z

Rank 5: a.y

Rank 6: b.x

In Fig. 9, these ranks are indicated next to element identifiers. The update module mentioned previously can operate quite efficiently if it adopts a bottom-up method by starting with content variables with the lowest rank and working upward following the pre-established ranking of content variables. Furthermore, since content variables with the same rank do not depend on each other, they can be updated concurrently.

The "dependency clause interpretation module" is a part of the update module that, as update-ready content variables get determined, whether the determination is top-down or bottom-up, updates corresponding active elements using relevant dependency clauses. Thus, a bottom-up method can be realized via the dependency clause interpretation module using the update-ranking module to find update-ready variables, whereas a top-down method can be built via the dependency clause interpretation module using recursive search to find update-ready variables. Fig. 13 shows a form of the content net update propagation system using a bottom-up method. In Fig. 13, if we replace the update-ranking module by a module that recursively identifies update-ready

variables, and a ranked update candidate set by a set of update-ready variables, we will have a form of the content net update propagation system based on a top-down method.

For each content file of a given content net, we assume a "style file" that defines a layout for this content file. We also assume that a content file and its associated style file are separate files. But, this is only one form of content nets, and it is possible to have a form of content nets where layout styles and contents are mixed in one file as in HTML documents. A "process station", or simply "station" is a content file with presentation layout separately defined via a style file (or inseparably mixed within the content file via a language such as HTML). A "process station net", or "station net", is a network of stations where each station is associated with a content file of a base content net (see Fig. 12). In these definitions, we assume that presentation layout respects intended structures and functions of process stations, which we will discuss next. We will then describe how elements of a content file map to components and functions of the layout structure of the corresponding process station.

Structurally, a station consists of one or more ports, which are of the following types (see Fig. 11):

- Reference ports

- Internal reference ports: Ports for receiving reference information, via interpretation through dependency clauses, from other ports within the station net.
- External reference ports: Ports for receiving reference information, via interpretation through dependency clauses, from sources external to the station net.

- Input ports

- Initial ports: Ports for submitting initial updates and triggering subsequent update propagation.
- Local ports: Ports for keeping information within the station for local use.

Each port can have one or more "control functions".

Control functions are either basic functions or composite functions assembled from basic functions. Basic functions include the following:

- Internal update: Update propagation throughout the content net following dependency chains given by dependency clauses.
- Import: Moving information into the content net from external sources.
- Export: Sending information to external destinations outside the content net.

In order to assemble composite functions from basic functions, stations provide some "control assemblers" including the following:

- Sequential execution: denoted by symbol " | ".
- Concurrent execution: denoted by symbol " & ".

Some examples of composite functions follow:

- Import | Internal Update: Perform "Import" and then "Internal Update".
- Internal Update & Export: Perform "Internal Update" and "Export" concurrently.
- Import | (Internal Update & Export): Perform "Import" and then "Internal Update" and "Export" concurrently.

Furthermore, control functions, basic or composite, can have "control modes", which include the following:

- Operator Control: Control functions with this mode can only be initiated by human users;
- Program Control: Control functions with this mode are initiated by computer programs.

Given a content file, an element with a dependent variable is called an "internal reference element". A set of internal reference elements of a content file sharing the same set of initial elements as dependency sources may be mapped to an internal reference port of the corresponding station. In many cases, such a set of internal reference

elements contains only a single element, and hence a single internal reference element maps to an internal reference port. Elements in a content file with free variables are of two types, namely "initial elements" and "external reference elements". A set of initial elements of a content file within the same update scope will be mapped to a initial port of the corresponding station. In some cases, such a set of initial elements might contain only a single element. An external reference element will be mapped to an external reference port. The set of all non-active elements that are not sub-elements of an active element will be mapped to the local port of the station.

Given a content file, a corresponding style file can be constructed following the mappings described above. For representation of style files, Web-standard languages such as XSL can be used. Some Web browsers support such style specification languages including XSL. If content files of a content net and their corresponding style files are given to such browsers, a network of process stations can be realized over the Web.

Whether style files are separate from content files or mixed with content files as in HTML files, a network of process stations as port complexes can coordinate work processes via message passing on the basis of the underlying content net

update propagation system. Such a collection of networked stations will show the following characteristics and benefits:

- Since a collection of related ports can be realized within the same Web document, the user, in moving between related ports, would not have to download and go back and forth between different Web documents. Also, since layout of multiple ports can be organized as layout of a single document, it is much easier to closely locate ports that are strongly related to each other in terms of contents and tasks.
- Update propagation of information contents at various ports can be realized through a Web-implemented station net. Such a Web-based system will enable timely coordination of human and computer-based tasks by real-time dissemination of information contents properly customized to the needs of those tasks.

Typically, a station net contains multiple stations, and supports coordination of multiple tasks by multiple people. However, as a special case, a station net may contain only a single station. All previous definitions and descriptions related to station nets still apply to this special case. For instance, in the order-placing task discussed earlier, it is possible to have a station net

consisting of a single "order-placing station". Such a station may have, as initial ports, a port for submitting credit card information, a port to enter order contents, or a port to enter search keys for browsing product catalogues. As internal reference ports corresponding to some of these initial ports, the station may have a port for placing the result of credit card examination, a port for presenting a response to the placed order, and a port for showing the result of requested catalogue search. In this case, the relationships between initial ports and their corresponding internal reference ports may be captured computationally through dependency clauses. For instance, a program to process credit card information can be represented as a MathML external function (defined by the user), in which case this function appears in the third term of the dependency clause that defines the content of the internal reference port for placing the result of credit card examination. Moreover, by placing both the initial and reference ports related to credit card approval, the user of the order-placing station can receive the approval result in a port right next to the initial port in the same screen.